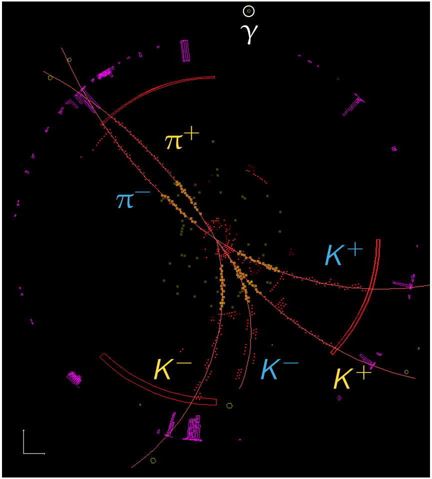
D_s Hadronic Decays from CLEO-c



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CLEO Collaboration

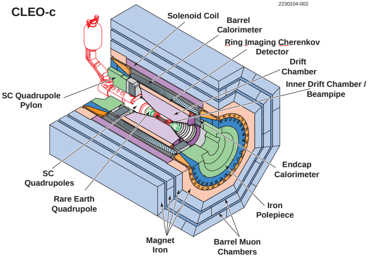
DPF/JPS, 31 Oct 2006

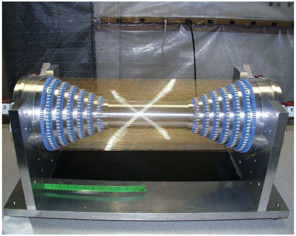
Cornell University
Laboratory for Elementary-Particle Physics

Outline

- Analysis techniques
- Results
  - Absolute D_s branching fractions
  - $D^0/D^+/D_s \to (\phi, \eta, \eta')X$

Other open-charm hadronic decays will be covered in the next talk by Steve Stroiney.



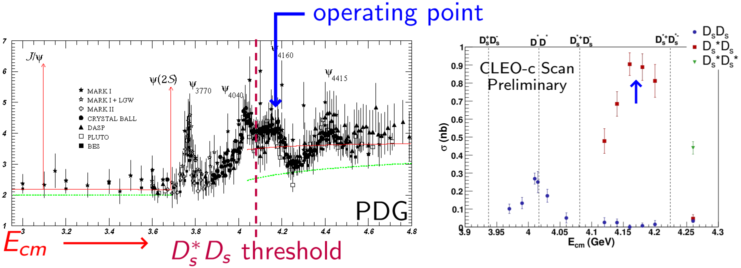


- Detector slightly modified from Υ physics configuration: silicon vertex detector replaced with (all stereo) drift chamber
- DAQ, trigger, software, etc. from CLEO-III with only minor changes
- Particle ID (from dE/dx, Čerenkov) better due to lower p tracks
- Tracking: $\delta p/p = 0.6\%$ at 1 GeV
- CsI calorimeter: $\delta E/E = 4\%$ at 100 MeV

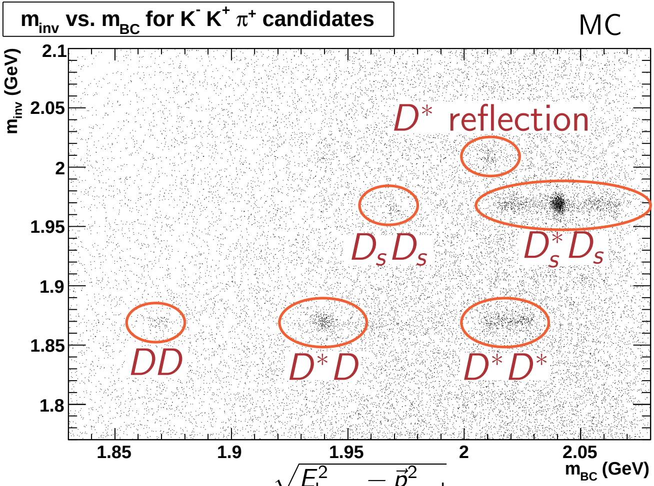
Dataset

D_s analyses use $\approx 200\ \text{pb}^{-1}$ of data taken near $E_{cm} = 4.17$ GeV.

- $\sigma(D_s^* D_s) \sim 1$ nb
- $\sigma(D_s D_s)$ too small to be useful
- $\sigma(DD + D^*D + D^*D^*) \sim 7$ nb



Kinematic Separation at $E_{cm} = 4.17$ GeV



$\sqrt{E_{beam}^2 - \vec{p}_{cand}^{\,2}}$

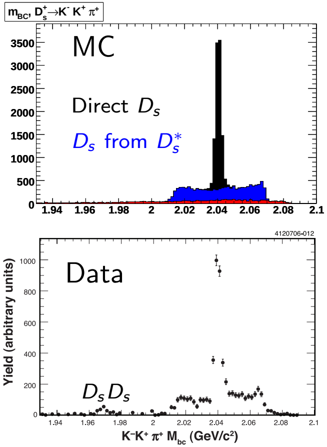
Reconstruction

- Daughter requirements:
  - Charged K, π distinguished using dE/dx (all momenta) and Čerenkov (for high momentum)
  - Find π^0 and η candidates by combining pairs of isolated showers in the CsI calorimeter ($\sigma_{m_{\pi^0}} \sim 6$ MeV, $\sigma_{m_\eta} \sim 15$ MeV)
  - Reconstruct $K_S \to \pi^+\pi^-$ and $\eta' \to \pi^+\pi^-\eta$
- $D_s^* D_s$ events kinematically separated from other open charm
  - We use

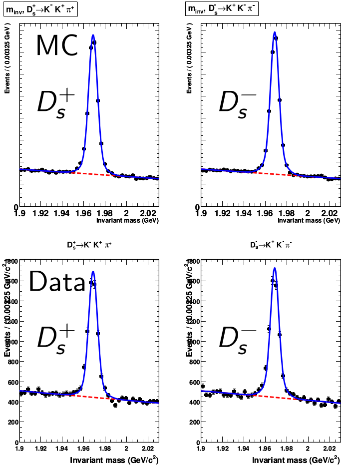
$$m_{BC} \equiv \sqrt{E_{\text{beam}}^2 - |\vec{p}_{\text{cand}}|^2}$$

    as a proxy for momentum to choose the $D_s^* D_s$ two-body decay
  - D_s candidates from $D_s^* \to (\gamma, \pi^0) D_s$ have smeared momenta and appear as a broad distribution in m_{BC}; directly produced D_s candidates form a sharp peak
  - We do *not* reconstruct the γ or π^0.
  - Fits are in invariant mass

Observed Kinematics in $D_s^+ \to K^- K^+ \pi^+$



Beam-constrained mass



Invariant mass

Absolute D_s Hadronic Branching Fractions

Why absolute D_s branching fractions?

- Measurements of decays to c quarks depend on reconstructing $D_{(s)}$ decays
- Branching fraction measurements can be limiting systematics
  - Since $b \to c$ is a dominant decay mode, B measurements often rely on knowing various $D_{(s)}$ BFs
  - Affects precision measurements of $Z \to c\bar{c}$, $H \to c\bar{c}$, ...
- Reference modes ($D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D_s^+ \to \phi\pi^+$) normalize virtually all other D branching fractions

D_s Hadronic Decay Overview

- The classic reference decay has been the exclusive mode $D_s^+ \to \phi\pi^+ \to K^- K^+ \pi^+$
  - Essentially all other decays have branching ratios to this mode
- This causes problems since ϕ signal is ambiguous given the precision we will soon achieve
- **We instead measure the total $K^- K^+ \pi^+$ branching fraction. No $\phi\pi^+$ result will be presented in this talk.**

Modes used

Decay	PDG 2006 BF (%)
$D_s^+ \to K_S K^+$	2.2 ± 0.45
$D_s^+ \to K^- K^+ \pi^+$	5.2 ± 0.9
$D_s^+ \to K^- K^+ \pi^+ \pi^0$	—
$D_s^+ \to \pi^+ \pi^+ \pi^-$	1.22 ± 0.23
$D_s^+ \to \pi^+ \eta$	2.11 ± 0.35
$D_s^+ \to \pi^+ \eta'$	4.7 ± 0.7

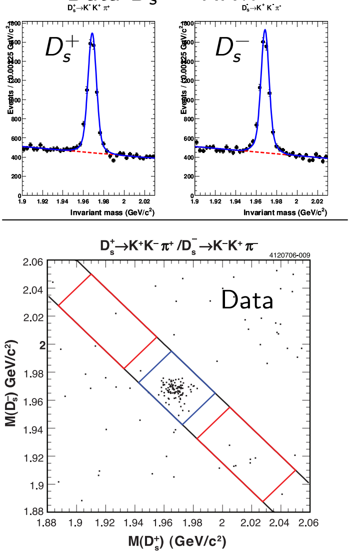
Relative uncertainties are 15–20%, and are all limited by the $\phi\pi^+$ BF (13.6%).

Recent BaBar measurements:
PRD **71**, 091104 (2005);
PRD **74**, 031103(R) (2006)

Analysis Method

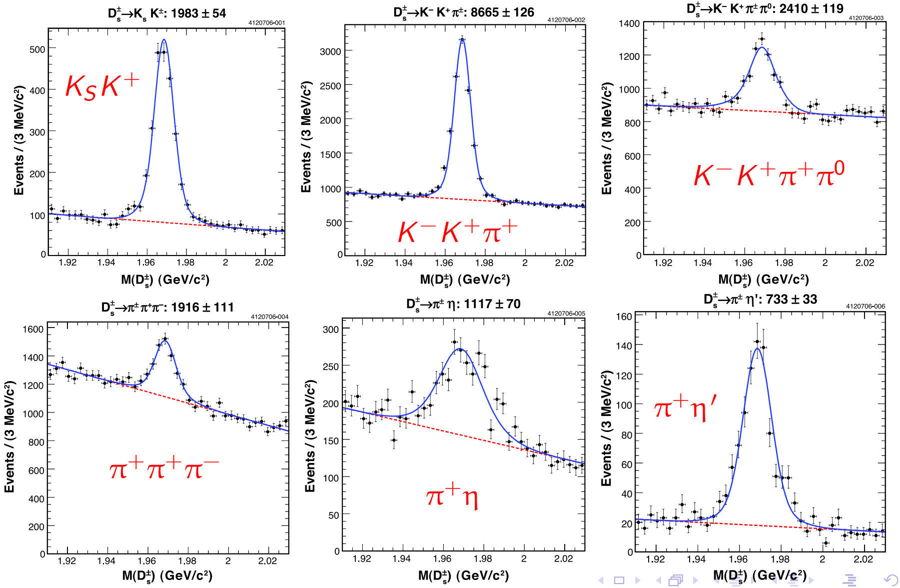
- Uses both **single tags** (one D_s reconstructed) and **double tags** (both D_s reconstructed)
- Core idea: $\mathcal{B}$ = ratio of efficiency-corrected double tag and single tag yields
- We do a binned maximum likelihood fit for all the observed yields (utilizing Poisson statistics for double tags)
  - Simultaneous fit among all modes maximizes statistical power
  - Dominant statistical uncertainty on every branching fraction is $\approx \sqrt{N(\text{total double tags})}$, so every double tag mode helps every BF

Data $D_s \to KK\pi$

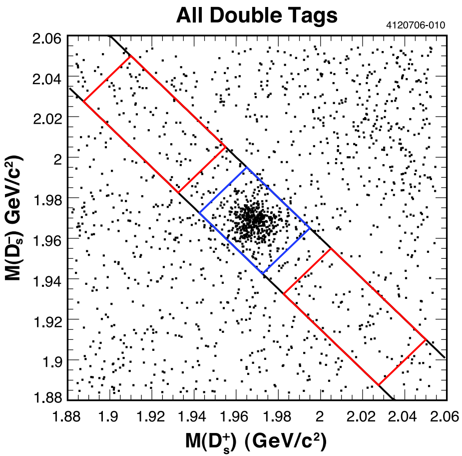


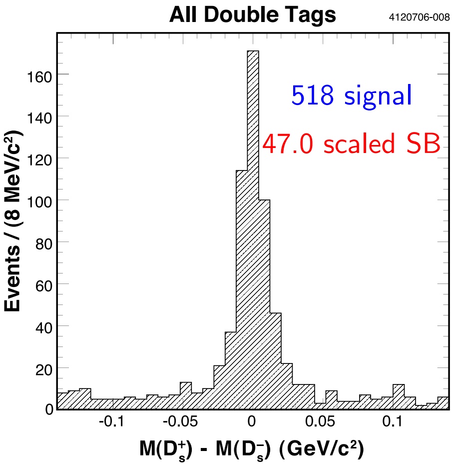
- Fit single tag signals with double Gaussian or Crystal Ball function (parameters fixed from Monte Carlo) plus a linear background
  - Each charge done separately
- In double tags, count events in signal and sideband boxes
  - Combinatoric background is flat in $m(D_s^+) - m(D_s^-)$, has structure in $m(D_s^+) + m(D_s^-)$

Data Results: Single Tags



Data Results: Double Tags





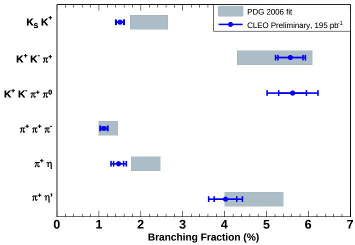
Systematic uncertainties

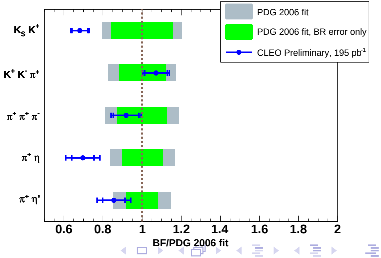
Source	Fractional uncertainty (%)
Tracking/K_S/π^0/η	0.35/1.1/5.0/5.0 per particle
Particle ID	0.3–1.4 correlated by decay
Resonant substructure	0–6.0 correlated by decay
Single Tag lineshapes	0.1–11.1 per mode
Initial state radiation correction	1.0 for $\pi\pi\pi$, $KK\pi\pi^0$ ST
Event environment	0–3.0 per mode

Absolute Branching Fraction Results

Preliminary

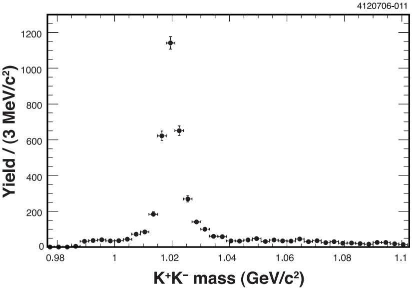
Mode	Fit (%)	PDG 2006 fit (%)
$\mathcal{B}(K_S K^+)$	$1.50 \pm 0.09 \pm 0.05$	2.2 ± 0.45
$\mathcal{B}(K^- K^+ \pi^+)$	$5.57 \pm 0.30 \pm 0.19$	5.2 ± 0.9
$\mathcal{B}(K^- K^+ \pi^+ \pi^0)$	$5.62 \pm 0.33 \pm 0.51$	—
$\mathcal{B}(\pi^+ \pi^+ \pi^-)$	$1.12 \pm 0.08 \pm 0.05$	1.22 ± 0.23
$\mathcal{B}(\pi^+ \eta)$	$1.47 \pm 0.12 \pm 0.14$	2.11 ± 0.35
$\mathcal{B}(\pi^+ \eta')$	$4.02 \pm 0.27 \pm 0.30$	4.7 ± 0.7





The $\phi\pi^+$ problem

- The process $(f_0(980) \to K^- K^+)\pi^+$ will contribute to any ϕ mass region, with badly controlled parameters
- Correction depends on experiment's mass window, resolution, angular distribution requirements!
- We have clear evidence for scalar $K^- K^+$ production
- We produce partial $K^- K^+ \pi^+$ branching fractions for 10 and 20 MeV windows on each side of the ϕ mass – 14% difference...



Preliminary

BF	Result (%)
$\mathcal{B}_{10}$	$1.98 \pm 0.12 \pm 0.09$
$\mathcal{B}_{20}$	$2.25 \pm 0.13 \pm 0.12$

$D^0/D^+/D_s \to (\phi, \eta, \eta')X$

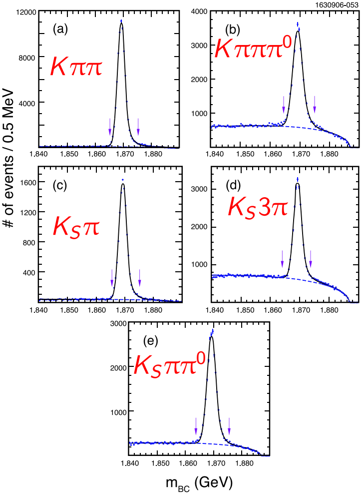
- Inclusive D^0/D^+ branching fractions to mesons with large $s\bar{s}$ content extremely poorly known
- Cabibbo-favored D_s final states have more $s\bar{s}$ content, hence expect larger η, η', ϕ branching fractions
- Inclusive rates help disentangle decay chains through open charm ($\to$ e.g. understand B_s from $\Upsilon(5S)$)
- Uses 281 pb^{-1} of 3.77 GeV data for D^0/D^+ and 200 pb^{-1} of 4.17 GeV data for D_s

$D^0/D^+/D_s \to (\phi, \eta, \eta')X$

- Strategy: find $D^0/D^+/D_s$; reconstruct ϕ, η, η' with remaining showers and tracks
  - $\phi \to K^- K^+$
  - $\eta \to \gamma\gamma$
  - $\eta' \to \pi^+\pi^-\eta \to \pi^+\pi^-\gamma\gamma$
- Count number of tags with fits in invariant mass (D_s) or m_{BC} (D^0, D^+)
- Use sidebands in invariant mass (D_s) and

$$\Delta E \equiv E_{cand} - E_{beam}$$

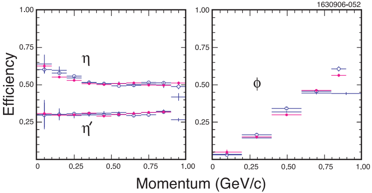
  (D^0/D^+) of the tag to get the background spectrum
- Fit invariant mass of ϕ and η, and $\eta' - \eta$ mass difference

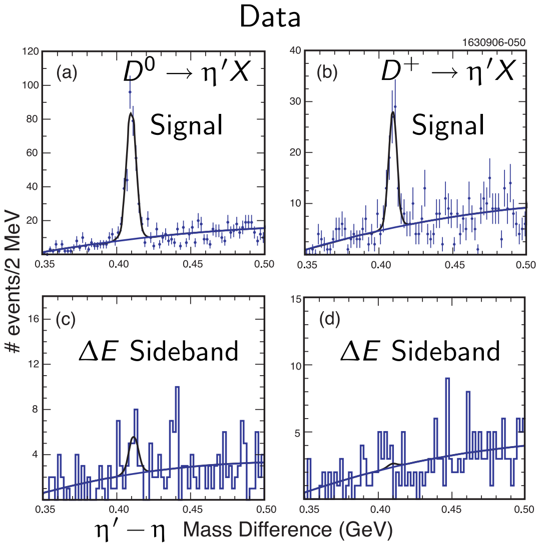


m_{BC} spectra, D^+ tags

Fits shown for D^0, $D^+ \to \eta' X$

Fits for η, ϕ done in momentum bins to account for efficiency variation





$D^0/D^+/D_s \to (\phi, \eta, \eta')X$

	$\mathcal{B}(\phi X)$ (%)		$\mathcal{B}(\eta X)$ (%)		$\mathcal{B}(\eta' X)$ (%)	
	This result	PDG	This result	PDG	This result	PDG
D^0	$1.05 \pm 0.08 \pm 0.07$	1.7 ± 0.8	$9.5 \pm 0.4 \pm 0.8$	< 13	$2.48 \pm 0.17 \pm 0.21$	
D^+	$1.03 \pm 0.10 \pm 0.07$	< 1.8	$6.3 \pm 0.5 \pm 0.5$	< 13	$1.04 \pm 0.16 \pm 0.09$	
D_s	$16.1 \pm 1.2 \pm 1.1$	18^{+15}_{-10}	$23.5 \pm 3.1 \pm 2.0$		$8.7 \pm 1.9 \pm 1.1$	

- η signals include feeddown from η'
- All except $D^0/D_s \to \phi X$ are first measurements

hep-ex/0610008, accepted by PRD

Summary

- Excellent detector, clean events, and large data sample $\Rightarrow$ branching fractions for open charm decays with precision $\gtrsim$ world averages
- D Hadronic branching fraction measurements help normalize D and B physics
- CLEO-c plans on taking ~ 1 fb^{-1} of open charm data over the next two years, aims for absolute BF precision of 4% or better for D_s